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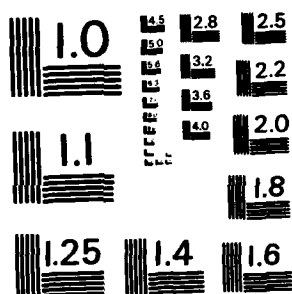
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*The effectiveness and influences of the
navigation ice booms on the St. Marys River*

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Cover: Aerial photo of the navigation ice booms on the St. Marys River. The west boom is on the right. Little Rapids Cut is in the background. Photo courtesy of the U.S. Army Engineer District, Detroit.

CRREL Report 84-4

January 1984



The effectiveness and influences of the navigation ice booms on the St. Marys River

Roscoe Perham

Prepared for
U.S. ARMY ENGINEER DISTRICT, DETROIT
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| Ice breaking | Ice movement | | | | | | | | | | | | | |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>Ice problems developed in the Sault Ste. Marie, Michigan, portion of the St. Marys River because of winter navigation. Passing ships and natural influences moved ice from Soo Harbor into Little Rapids Cut in sufficient quantities to jam, cause high water in the harbor, and prevent further ship passage.</p> <p>After physical model and engineering studies, two ice booms with a total span of 1375 ft (419 m) with a 250-ft (76-m) navigation opening between were installed at the head of Little Rapids Cut in 1975. A modest field study program on the booms was conducted for the ensuing four winters to determine ice and boom interaction and the effects of ship passages on the system. Forces on some anchors were recorded and supplemental data were taken by local personnel.</p> | | | | | | | | | | | | | | |

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20. Abstract (cont'd).

> Several reports have been written about the booms' early operations. This paper presents a four-year summary of the main effects of the booms on ice and ship interaction and *vice versa*. Throughout the four winter seasons, the small quantities of ice lost over and between the booms were manageable. Ships usually passed through the boom without influencing the boom force levels, but at times they brought about large changes. One boom needed strengthening, and artificial islands were added for upstream ice stability. Coast Guard icebreakers were also a necessary part of winter navigation in this area.

PREFACE

This report was prepared by Roscoe E. Perham, Mechanical Engineer, Ice Engineering Research Branch, Experimental Engineering Division of the U.S. Army Cold Regions Research and Engineering Laboratory.

This study was funded by the U.S. Army Engineer District, Detroit, Michigan, under contract no. NCE-~~IA~~A-80-28EK, *St. Marys River Ice Boom Monitoring*.

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THE EFFECTIVENESS AND INFLUENCES OF THE NAVIGATION ICE BOOMS ON THE ST. MARYS RIVER

Roscoe Perham

INTRODUCTION

A federal program to demonstrate the feasibility of winter navigation on the Great Lakes-St. Lawrence Seaway was authorized by Congress in 1970. Part of the program included voyages extending beyond the normal navigation season, which traditionally was suspended from 15 December to 1 April. Ice problems developed in the Sault Ste. Marie, Michigan, portion of the St. Marys River because of this winter navigation. To prevent ships from moving large quantities of ice from Soo Harbor into Little Rapids Cut, which caused ice jamming, two ice booms were placed at the head of Little Rapids Cut in 1975. This report provides a four-year summary of the performance of these booms.

ST. MARYS RIVER

The St. Marys River is an important connecting channel in the Great Lakes Waterway, which joins

Lake Superior with Lake Huron. The Soo Locks at Sault Ste. Marie, Michigan, are located at the mouth of Lake Superior and all ships exiting the lake must pass through these locks. Figure 1 is an aerial view of the locks, looking downstream over the broad 2-mile-long (3.2 km) Soo Harbor. Besides the locks, three small hydroelectric plants and a compensating works control the water flow out of the lake.

Ships bound for the lower Great Lakes leave the east end of Soo Harbor via the Little Rapids Cut. The upstream end of this 600-ft-wide (183 m) navigation improvement is seen in the right background of Figure 1. A diagram of the area is shown in Figure 2. The width of Little Rapids Cut is fairly constant for a distance of more than 2 miles (3.2 km) downstream, where the river begins to widen into Lake Nicolet. The area of ice and ship activity affecting Little Rapids Cut is shown in Figure 2. Of particular importance are the angle turn between courses 1 and 2 and the car ferry route in Little Rapids Cut that connects Sugar Island with the mainland.



Figure 1. Aerial view looking downstream with the Soo Locks in the foreground, Soo Harbor center left, and the head of Little Rapids Cut in the background right. Sault Ste. Marie, Michigan, right; Ontario left. Photo courtesy of U.S. Army Engineer District, Detroit.

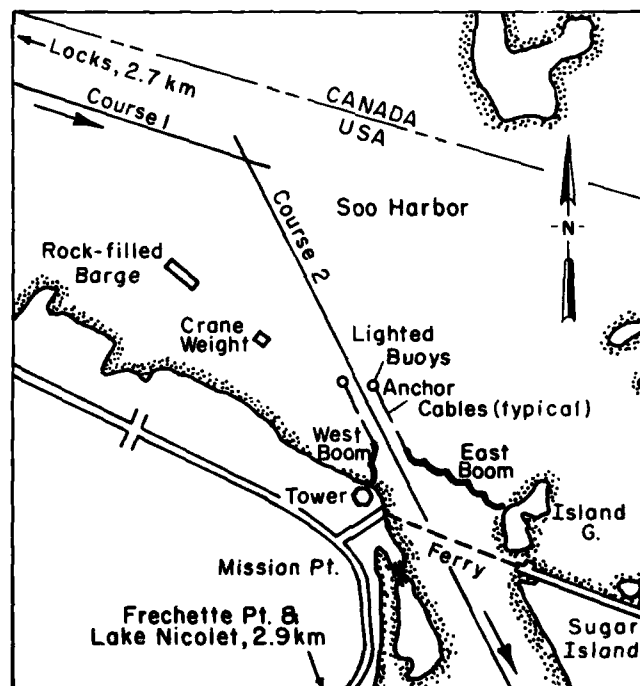


Figure 2. East end of Soo Harbor and head of Little Rapids Cut showing navigation courses and ferry track.

ICE PROBLEMS

After an ice cover forms on Lake Nicolet, the upstream edge of the pack ice progresses from south to north in the Little Rapids Cut. In time it generally reaches the ferry track and disrupts the ferry's schedule or stops the craft altogether. Coast Guard icebreakers are then requested to flush ice from the ferry docks and generally move it downstream.

As might be expected, ships passing through Soo Harbor in winter keep the ice broken and relatively unstable. Cross-harbor traffic, sizable thermal effluents, and water level changes contribute further to this condition. At times ice is blown out of the harbor by storms without any assistance from water currents and ships. A great area of open water is created in which skim ice and slush can rapidly form and move downstream. Before emplacement of the ice booms it was found that an unimpeded supply of ice could cause ships to become stuck in Little Rapids Cut. The backwater effects from ice jams would cause flood levels in Soo Harbor.

REMEDIAL MEASURES

The need to prevent or appreciably reduce the amount of ice releases into Little Rapids Cut led to a study of several ice control schemes. A physical, hydraulic model of Soo Harbor and Little Rapids Cut, which utilized plastic pellets with a surface treatment to simulate the ice, was constructed (Acres American 1975, Cowley et al. 1977). A structure at the location and of the extent shown in Figure 2, at the head of Little Rapids Cut, was found to minimize ice migration. Ice booms were selected to be placed here because they worked well in the model, were relatively inexpensive, and could be completely removed in the spring.

The ice booms have several lines of floating timbers held in place by wire rope and buried anchors. The timbers are Douglas fir $1 \times 2 \times 20$ ft ($0.3 \times 0.61 \times 6.1$ m). Floats support the structure at junction points. The installed booms are shown restraining ice in Figure 3. Each boom segment spans 200 ft (61 m), and the navigation opening is 250 ft (76 m) wide.

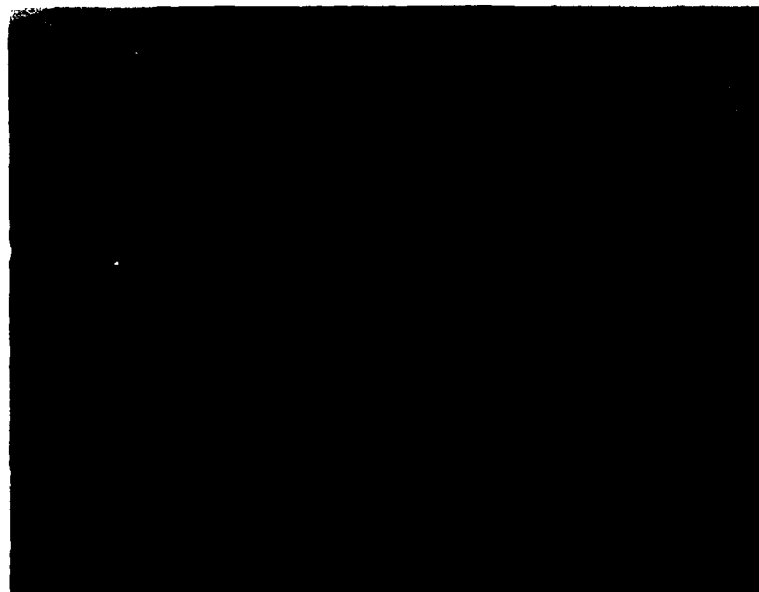


Figure 3. Aerial photo of ice booms with Little Rapids Cut in background. West boom on right. Photo courtesy of U.S. Army Engineer District, Detroit.

FIELD STUDIES

The original design of the booms was based on early studies of the St. Lawrence River (Perham 1974, Perham and Racicot 1975). Several anchor lines of the boom structures were instrumented for forces to gain a better understanding of ice, ship, and ice boom interaction. Supplemental data, such as those for wind and temperature, were also obtained.

Force levels were continuously recorded and Corps of Engineers personnel monitored the force measurements during the normal work week and occasionally for longer time periods. The probable cause of a force change (e.g. a ship passage, wind, or some other event) was recorded. The location of the ice pack in Little Rapids Cut, ships' speeds, ice movement and thickness, and so forth, were also recorded. The scope of this report is not sufficient to present all of the information obtained, but supplemental reports will be prepared as time permits.

HIGHLIGHTS, TRENDS, AND MAJOR FINDINGS

Modifications to booms

The design and operation of the ice booms during the first two years are covered in earlier reports (Perham 1977, 1978). It was seen that the ice cover behind the east ice boom remained stable during all four winters. The ice cover behind the west ice boom, however, could break free from shore as a single sheet for a length of as much as $1\frac{1}{2}$ miles (2.4 km) and apply forces that damaged some components of this boom. The site plan of the major components of both booms is shown in Figure 4. The worst case occurred on 20 January 1977 when two minor cables (3 and 3' in Fig. 4) and the main shore anchor (4 in Fig. 4) broke; the damage was caused by ship, ice, and boom interaction. Very large forces were applied because the boom timbers were frozen into the ice.

After the first winter, an anchor line (3') was added to the center of the west boom. After the second winter, the two small anchor lines (3, 3') were strengthened. Before the third winter, a 300-ton barge and six crane weights totaling 95 tons were positioned in shallow water upstream, as shown in Figure 2. In addition, a technique for breaking timbers free from the ice when high loads appeared imminent was initiated prior to the third winter: a small tug would approach from downstream and run her bow up onto the edge—that

was all it took. This equipment and the timber-freeing technique have prevented further breaks. A large ice sheet can still break free between the ship track and the barrier formed by the barge and weights. One such sheet, about 655×2950 ft (200×900 m), is shown in Figure A3. It is much smaller than the earlier ones and has not caused damage, but the potential for damage may still be there.

Maximum forces

The maximum forces developed in the instrumented anchor lines are summarized in Table 1. Each column is identified by an anchor line number that is also shown in Figure 4. The suffixes E and W mean east and west booms respectively.

These forces usually developed when ice was moving over the boom. The ice would seem to engage part of the boom and then break free quickly. The forces might take 2 to 4 minutes to develop, but their release would take only seconds.

The maximum load of 160 kips (710 kN) on 1E developed in 1975-76 when a large ice sheet moved over the west boom from natural forces and impinged on the east boom. Prior to this impact, the sheet had displaced a float from the west boom with a measured resultant force of 88 kips (391 kN). The other seasonal maximums for 1E averaged only 34 kips (150 kN); the original force estimate for this anchor was 43 kips (191 kN).

SHIP TRAFFIC

Characteristics

Ship traffic through the boom was randomly sampled by Corps of Engineers personnel. Personnel could not be at the boom site all of the time and therefore the number of observations does not include all transits.

Icebreakers frequently worked in the angle turn and in the ice pack of the cut. The need for icebreakers in the St. Marys River is indicated by the following: during 1977-78, 39% of the 290 ships observed were icebreakers, and in 1978-79, 30% of the 171 ships observed were icebreakers. On many days over half the passages were made by icebreakers.

The size of merchant ships passing through the booms varied from 324 ft long \times 49 ft wide (99×15 m) to 1000×105 ft (305×32 m). They

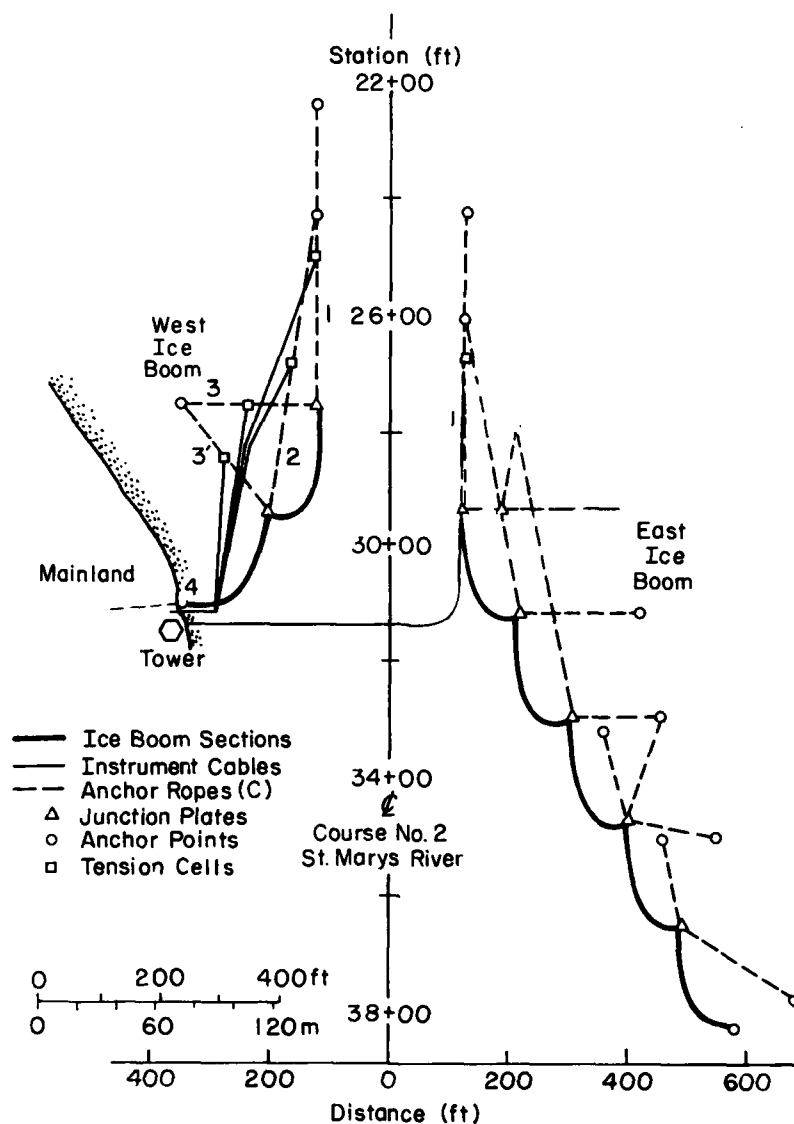


Figure 4. Plan view of ice booms showing anchor lines (numbered) and force sensor locations.

Table 1. Maximum forces developed in selected ice boom anchor lines.

| | Anchor line | | | | | | | | | | | |
|---------|-------------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| | 1W | | 3W | | 2W | | 3'W | | 4W | | 1E | |
| Winter | (kip) | (kN) | (kip) | (kN) | (kip) | (kN) | (kip) | (kN) | (kip) | (kN) | (kip) | (kN) |
| 1975-76 | 77 | 340 | 53 | 240 | 94 | 420 | — | — | — | — | 160 | 710 |
| 1976-77 | 89 | 400 | 39 | 170 | 52 | 230 | 90* | 400 | 190* | 840 | 33 | 150 |
| 1977-78 | 64 | 280 | 35 | 100 | 34 | 150 | 59 | 260 | — | — | 34 | 150 |
| 1978-79 | 44 | 200 | 50 | 220 | 27 | 120 | 74 | 330 | 18 | 80 | 34 | 150 |

kip = 1000 lbf

* Estimated from failure.

averaged about 700 ft (213 m) in length and were mainly iron ore carriers, with occasional fuel carriers. The average speed through the boom opening of upbound ships was 9.7 ft/s (2.9 m/s) for 44 observations. The average speed of downbound ships was 12 ft/s (3.7 m/s) for 81 observations. The minimum speed was 2.8 ft/s (0.85 m/s) and the maximum was 18.3 ft/s (5.6 m/s).

Effect on boom forces

The first-year effects of ice and ships on the control booms have been described (Perham 1978a, b). The effects during the ensuing years were similar but the forces were generally lower. Of the 389 observed passages during 1977-78 and 1978-79, only 70 ships, or 18%, caused changes in boom loading; of these only 21, or 5% of the total, were considered sizable. Using the 1W anchor line for reference, the force level could vary from a few kips up to about 50 kips (220 kN), with an average of 25 kips (111 kN), for 1977-78, and up to 25 kips (111 kN), with an average of 14 kips (62 kN), for 1978-79. Ships hit the booms on four occasions, but boom repairs were made within a day. A force of 24 kips (107 kN) was measured during one contact, but the others occurred where no instruments were located or when the instruments were not energized.

Effect on ice

During much of the winter navigation season, ships need to break ice to get through Soo Harbor. It is especially difficult to negotiate the angle turn, and extra forces and icebreaking have to be applied there. On occasion ships cause ice to go over the boom. More often the ships release a quantity of brash ice that moves down the ship track and through the boom opening.

The ice movement data for 1978-79 were studied carefully in an attempt to estimate the amount of ice that actually passed the boom, either through the opening or over the boom itself. Ice moved or flowed during only a short portion of the winter, and ice moved over the west boom for only a fraction of the time that it did through the opening. The quantities of ice passing each location, however, turned out to be roughly the same. The reason for this similarity was that the ice going over the boom was solidly packed sheet ice, while the brash ice in the much narrower ship track was loosely packed or scattered. The total ice was estimated to be roughly equivalent to one third of the complete Soo Harbor ice cover (about 12×10^6 ft² (1.1 km²) although the actual quantities were probably larger. Nonetheless, the quantity of ice was restrained from entering Little

Rapids Cut sufficiently well to eliminate problems with ice jamming there. More information may be forthcoming on this subject.

CONCLUSION

The ice control measures applied to Soo Harbor have improved winter navigation (U.S. Army Engineer District, Detroit 1979), although ice-breakers have always been there to help out. The application of ice booms in this location was basically sound, as was their design. The artificial islands (barge and weights) are a vital necessity, and one more stabilization device, preferably a floating one such as a short boom, should be located inside the angle turn near the ship track but a safe distance away from it. With this addition, ice control should be complete.

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APPENDIX A: ICE BOOM FORCES

Introduction

The boom forces study program and its major results are in the main text of this report, and a substantial amount of information on forces is available in the references as well. This appendix provides a few details of how the forces on the boom develop and how they are altered by the passing of ships. Most of the early force information is in terms of the load on anchor line 1W. Instrumentation changes have permitted the total force on the west boom structure to be calculated at certain times. The corresponding values for anchor line 1W are presented for comparison.

Physical arrangement

Most of the ice activity outside of the ship track takes place behind the west boom, shown in Figure A1. The direction of boom forces on each anchor line is given; note that the direction of a ship heading downstream on course 2 is 153° . If the force level on each anchor line is known, then the magnitude and direction of the total ice force may be calculated.

The ice above the west ice boom is restrained by four objects: the ice boom, the shore line, the fixed structures called the barge and crane weights, and the ice on the opposite side of the shipping track (see Fig. 2). On occasion the wind may also restrain the ice, but it can have an opposite influence. The effect of the fixed structures can increase with time because the ice sheet that they stabilize becomes larger. However, the size of the area that they influence seems limited.

Total force development

A good example of force development behind the west boom came during the first 23 days of January 1978. The total ice force on the boom was calculated from the time of the initial, thin fragmented ice cover, about 3 in. (0.08 m) thick, until it was completely solid and about 12 in. (0.3 m) thick. Aerial photos taken 2 January 1978, for instance, show the ice cover to be solid. The total ice force in magnitude and direction is shown in Figure A2. The calculated values are based on measurements that were terminated on 23 January when the 3W force sensor became inoperative.

During the first week the force direction was

between 118° and 128° . The force angle gradually diminished until 18 January when the force was nearly parallel to course 1, or 109° . This direction was probably due to shore and ice interaction, because ice tends to pile up at the bend in the shoreline at Mission Point, above anchor cable 4. This ramp-like accumulation would deflect moving ice out toward the channel.

A large sheet of ice cracked free from shore on 16 January because of fluctuating water levels in Soo Harbor. The crack direction was parallel to the shore for about 200 ft (61 m) and then proceeded on a line to the crane weight and barge and out to the ship track. This ice floe was about 3000 ft (914 m) long and had an average width of 680 ft (207 m). The downstream end of the floe rested against the west boom and would rotate somewhat about this general point. River flow forces would cause the upstream end to move out into the ship track, and passing ships would in turn shove it back toward the barge and weights. Figure A2 shows that this event caused the direction of total force to take a more downstream orientation; the magnitude of the boom forces became decidedly higher then. However, it is not possible to determine exactly what the causes of the peak loads were. They could be impact loads or perhaps a lever and fulcrum type load resulting from a ship shoving the ice back against trapped ice.

The shape and size of this large ice floe are shown in Figure A3, which is an aerial photo taken on 18 January, just a few hours before the large force peak occurred. The ice floe is in contact with the west boom, the open water to its left is the ship track, and the open water to the right is where the ice floe was originally located. On the following day a tug was used to break the boom timbers free from the ice. At this same time the ice sheet was broken up and a substantial portion of it went over the boom; this accounts for most of the reduction in force levels on 19 January.

Passages of *Wolverine* and *Agawa Canyon*

The interaction between ice, ships, and the shoreline or other fixed ice is best exemplified by details of the passages of the ships *Wolverine* and *Agawa Canyon* on 18 January. The maximum total force developed on the boom during this

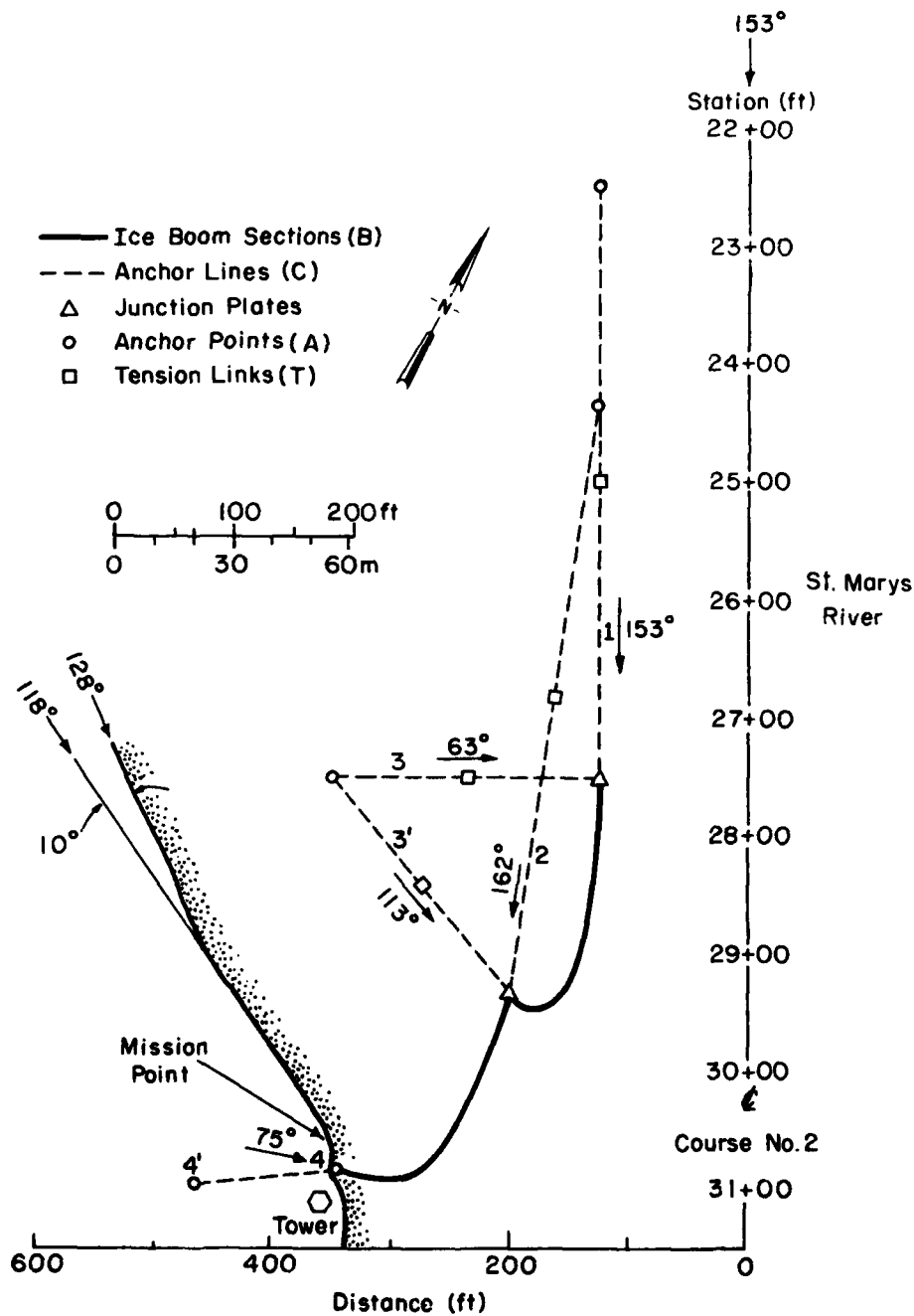


Figure A1. Plan view of west boom showing anchor lines (numbered) and force sensor locations.

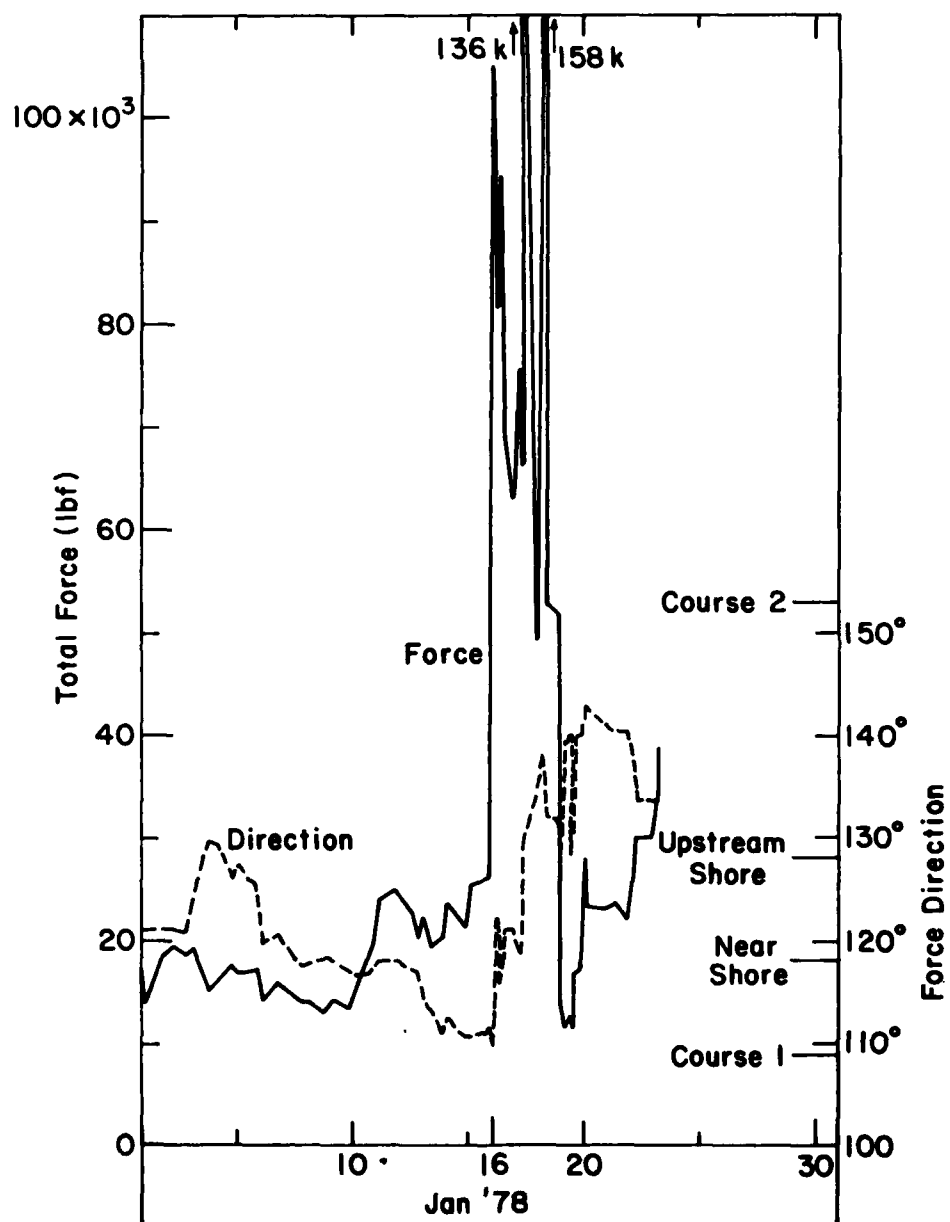


Figure A2. Total force and direction of force against the west boom in January 1978.

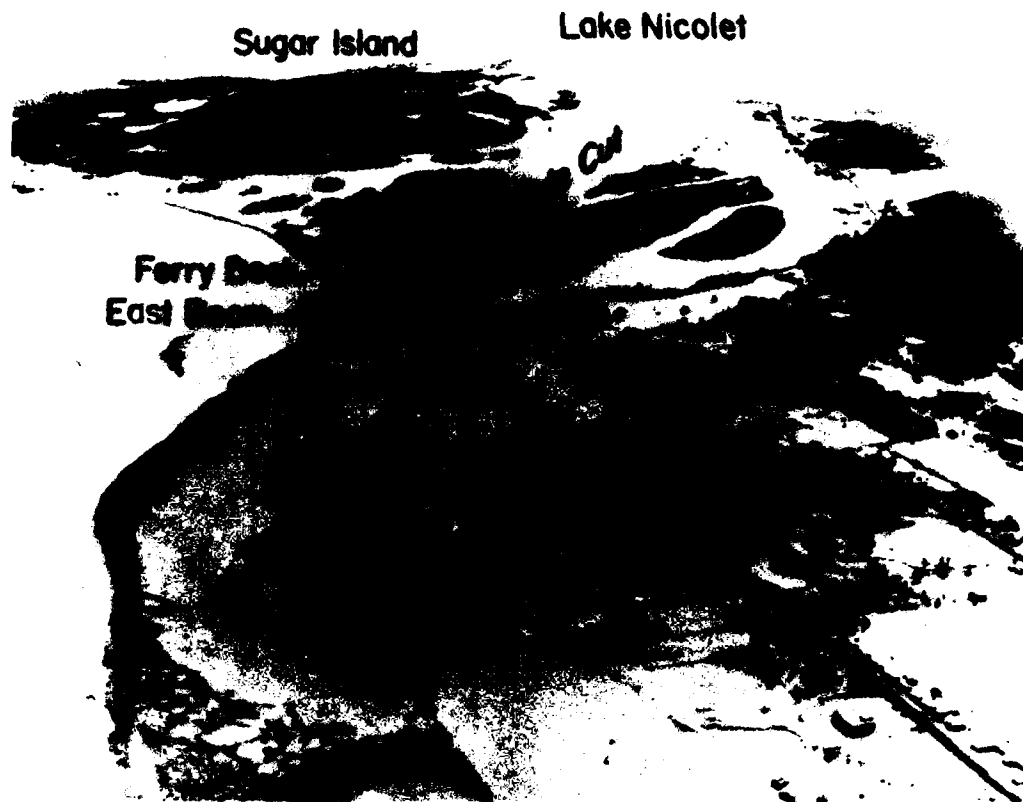


Figure A3. Aerial photo of Little Rapids Cut on 18 January 1978 showing large ice floe (left of center) lodged against west boom.

period was concurrent with passage of the latter. The *Wolverine* is 630 ft (192 m) long and 68 ft (20 m) wide; she passed upbound through the navigation opening at 1725 hr with speed of 11.6 ft/s (3.5 m/s). The *Agawa Canyon* is 647 ft (197 m) long and 72 ft (22 m) wide and passed downbound through the opening over 1 hour later at 1838 hr with a speed of 11.1 ft/s (3.4 m/s). The ships were similar in size and speed; the main differences were their direction and their approach. The *Wolverine* came into the Soo Harbor ice cover upbound from open water in the Little Rapids Cut. The *Agawa Canyon*, however, had been anchored earlier in the day near the Coast Guard base, about 11,700 ft (3.6 km) above the boom.

Copies of the traces from the force recorders for the west boom are combined in Figure A4. The initial load on 1W was 36 kips (160 kN). The *Wolverine* had little effect as it passed through the opening. A peak force developed 6 minutes later as the ship went past the end of the large ice sheet. The force on 1W decreased and fluctuated for

about 6 minutes, after which it rose and stayed above 45 kips (200 kN) for about 48 minutes. For most of this latter period, however, the *Wolverine* had completed its trip to the Soo Locks. The direction of the total force during this period was about 138°.

The largest force on 1W was 61 kips (271 kN), and it occurred at approximately 1827 hr when the downbound *Agawa Canyon* was about halfway from the Soo Locks to the boom opening. The action of the previous ship had the effect of loosening up the mid-harbor ice and the downbound *Agawa Canyon* pushed some of it downstream against the large rotatable ice sheet. The anchor forces were noticeably redistributed as the *Agawa Canyon* passed through the ice cover. The total force finally stabilized at a higher level, but the direction was about the same as it was before the two ships went by. The force on anchor line 1W was originally the largest of the five forces, but at the end of this ship activity, it was only average.

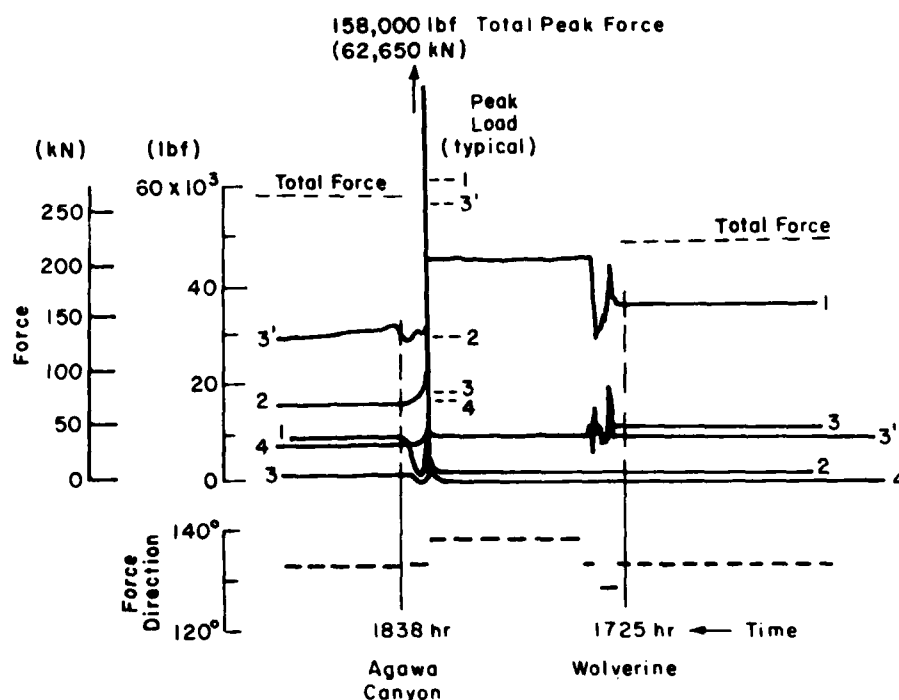


Figure A4. Force recorder tracings for west boom sensors from 19 January 1978 noting the effects of the passage of Wolverine and Agawa Canyon.

Table A1. Sampling of total forces on the west boom and on individual anchor 1W, January 1978.

| Date | Time | Total force | | 1W force | | Ratio |
|-----------------|------|-------------|------|----------|------|-------|
| | | (kips) | (kN) | (kips) | (kN) | |
| 1 Jan | 1015 | 17 | 76 | 7.1 | 32 | 2.4 |
| 16 Jan | 1310 | 105 | 467 | 38 | 169 | 2.8 |
| 16 Jan | 1630 | 94 | 418 | 32 | 142 | 2.9 |
| 17 Jan | 1709 | 136 | 605 | 64 | 285 | 2.1 |
| 17 Jan | 1930 | 50 | 222 | 32 | 142 | 1.6 |
| 18 Jan | 1840 | 158 | 658 | 61 | 27 | 2.6 |
| 18 Jan | 1930 | 53 | 236 | 9 | 40 | 5.9 |
| 23 Jan | 0800 | 30 | 133 | 2 | 9 | 1.5 |
| 23 Jan | 1715 | 30 | 133 | 12 | 53 | 2.5 |
| Design estimate | | 230 | 1023 | 65 | 289 | 3.5 |
| | | Avg 2.6 | | | | |

Force comparison

Table A1 gives selected values of total forces on the west boom and the corresponding forces on anchor 1W. This is done for purposes of comparison because most of the data shown in earlier reports refer only to the force on 1W. For the several examples from the winter of 1977-78, the total force averaged about 2.6 times the force on

1W. Looking back at the forces estimate for the initial design of the boom, the corresponding ratio was 3.5. These latter values, however did not consider the effects of consolidated and large broken ice sheets on the ice boom loading. It can only be assumed further that the ratio 2.6 applies to the other years as well.

Passage of Roger Blough and Munson

The total force on the west ice boom varied somewhat during the upbound passage of the *Blough*. Initially the force was 30 kips (133 kN) at 125°, and it rose to a peak of 48 kips (214 kN) at 130° about 12–14 seconds after the *Blough* went through the opening. The force intensity dropped quickly to a low of 6.6 kips (29 kN) at 137° for about 120 seconds and then began increasing in an erratic manner. In about 15 minutes, before forces stabilized, a second ship, the *Munson*, came up through the opening and caused more force changes. Fifty minutes later the forces were stable again, and the total force on the boom was 28 kips (125 kN) at 120°.

Discussion

One can only conjecture about the mechanism of force transfer. There could be the equivalent of levers and ramps in the ice and certainly impact loads. It was thought at first that the total force could be related to the water drag shear stress of

the rotatable ice floe. However, a much larger area of ice is necessary to reach the load levels measured. The force variations in the various anchor lines are undoubtedly due to ice-to-ice and ice-to-shoreline interactions.

Conclusions

1. Ships passing through the ice cover above the booms can appreciably vary the ice load on the boom.

2. The force measuring systems in the boom structure have provided valuable information on several ways that ice, booms, and ships affect the structure

3. The use of artificial "islands" upstream has reduced the levels of forces that develop in the boom; even the large piece shown in Figure A3 did not cause an overload. However, a piece this size is too large to remain frozen to the boom timbers yet be free to move sideways as it obviously has done. Potential for ice boom damage through ice-ship interaction is present.

A facsimile catalog card in Library of Congress MARC format is reproduced below.

Perham, Roscoe

The effectiveness and influences of the navigation ice booms on the St. Marys River / by Roscoe Perham. Hanover, N.H.: Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1984.

iv, 18 p., illus.; 28 cm. (CRREL Report 84-4.)

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